MAIN-RING BEAM SENSING

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Electromagnetic beam detectors form a vital part of the operating control system of an accelerator. They serve a wide variety of functions, and the cost of the complete system can be considerably reduced by limiting the flexibility of the system to that which is really needed.

Wide-Band Electrodes

These are needed to observe the bunching of the beam, bunch-shape oscillations, coherent transverse oscillations in various modes which could develop into instabilities, etc. The intrinsic resonant frequencies of the structures should be as high as possible, since with a 50-MHz radiofrequency system, there will be components worth observing above 200 MHz. The linearity of the system must be high, not because of large excursions of the beam, which are unlikely, but so that the electrodes average properly the various components of the beam. For example, position electrodes should give a signal proportional to the displacement of the center of charge of the beam. Only one of each type of electrode is needed, located at some point in the ring close to the control room so that the length of the high-quality transmission lines can be minimized. The needed electrode configurations are

(a) Monopole, or current sensing - the Q signal.

(b) Dipole or position sensing - x coordinate.

(c) Dipole - z coodinate.

(d) Quadrupole, sensing beam aspect ratio.

(e) Skew quadrupole, sensing vertical-horizontal coupling.

Electrodes with DC Response

A debunched beam would give no observable signal on normal beam-sensing electrodes. Using nonlinear properties of high-permeability alloys, it is possible to make a current transformer with response from dc up to hundreds of kHz. This would be a valuable signal, especially since it could be absolutely calibrated to measure the circulating charge. Only one such device would be needed in any case, primarily to aid in the adjustment of the extraction system.

Orbit-Shape Measurement

The aperture of the main ring is very small, and the orbit distortions which could be caused by expected alignment errors and magnet errors are quite comparable. The correcting-magnet system would be easily capable of achieving a circulating and accelerated beam up to moderate energies, but would be unable to correct for alignment errors at high energies. Some method must be available to quantitatively measure closed-orbit distortions. The data can then be analyzed for needed corrections to the accelerator alignment.

Horizontal position is best measured at the points where β_x is maximum. In fact, addional measurements at the radially defocussing quadrupoles have such a small weight in the calculation that they are virtually useless. Similarly, the vertical position would be measured where β_z is maximum. This means that there are about 100 of each type, giving five data points per betatron wavelength on the average. The bandwidth of the signal system need not be large--in fact the observation should ideally be an average over four turns (80 μs) so that the free betatron oscillations do not influence the result. It would be very desirable to have all of the observations made, all around the ring, essentially simultaneously, as the closed-orbit distrotions will change with magnet excitation. Assuming the four-turn average, a sequential measurement system would be too slow. A system which made observations at only one station per pulse would be frustratingly slow and would consume too much operating time if large adjustments turned out to be needed.

The vertical and radial position system should be capable of being triggered from the control room so that it measures, and stores somehow, the beam position all around the ring at once. If it could be so triggered several times in one pulse, the data would be even more significant. A gain-control system is needed to compensate for the wide range in circulating charge to be expected, independent of the form of the data readout used. The linearity of the difference electrodes is important for the same reason as in the wide-band system.

Electromagnetic beam-sensing electrodes give the product of the displacement of the centroid of the beam and the beam intensity. Some provision must be made for reducing the data to pure beam-position information. In addition, they do not give low-frequency information, and this has the effect of making the signals hard to interpret unless the bandwidth of the system is high enough to see the "baseline" between bunches clearly. If there are clear gaps in the beam, a fast switch closed at the right time can offset the ac axis so that zero output means centered beam, and the average over the signal, taken by low-frequency circuits, gives meaningful position information, including the sign of the displacement. A better system would be to make the position electrodes satisfactory for 50 MHz and at each location to include a 50-MHz current sensor (Q electrode of toroid). A coherent demodulator would then give an unambiguous beam-position signal. Provided that the bandwidth of the system is not too small, both the position electodes and current transformer could be resonant at 50 MHz. The question remains as to where the demodulator should be located. If it is alongside the electrodes themselves, the problem of signal transmission to the utility buildings would be simplified, but the provision of gain adjustment would be made more complicated. The problem of semiconductor components near the beam and the possible radiation damage resulting is an additional complication which needs to be evaluated.

Both from the point of view of data recording for future computation and for the construction of easily observed and interpreted oscilloscope displays, the best way to handle the position data would be to digitize it in the utility buildings and transmit it to the control room in that form. The eight position signals per house could be held on sample-and-hold circuits for an analogue multiplex circuit which connects to an analogue-to-digital converter. A time-sharing multiplex system could collect all of the information in the order of a millisecond. With this system, it would be possible to record the shape of the closed orbit at ten or twenty values of the proton momentum without difficulty, on one pulse.

During machine start-up, it is convenient to observe the radial position (and vertical position) of the first turn, or, in bad cases, the partial turn. A shortening of the averaging time would accomplish this without any other changes in the system.

Materials of Construction

The main-ring vacuum system will be constructed of refractory materials to the greatest extent possible. The maintenance of this system will be vastly decreased if it is possible to completely exclude organic materials. It is desirable, therefore, that the beam-sensing electrode system be constructed in this way, with soldered-in ceramic signal lead bushings, etc. We do not, however, plan to bake out the system at high temperatures. In general, we plan to put all equipment, such as electronic circuitry, in the utility buildings rather than in the tunnel. This will eliminate the radiation damage problem, and decrease the maintenance difficulties. There might be, however, technical requirements which would make this scheme difficult under some conditions. In these cases, it is essential that the circuits be built so that they may be quickly replaced in case of a breakdown.